Paper presented at the

S.A. INSTITUTION OF CHEMICAL ENGINEERS

Natal Branch

OPERATIONS RESEARCH SEMINAR

Durban, March 2nd, 1969

A COMPUTOR SIMULATION STUDY OF THE NEED FOR A BULK PRODUCT STORE

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OPSOMMING

Die gebruik van 'n wiskundige model om 'n bestuursprobleem op te los, word beskrywe. Die wiskundige model het as grondslag 'n stel wiskundige en logiese verwantskappe, wat tussen dele van die stelsel wat ondersoek word, bestaan. Hierdie verwantskappe word geprogrammeer en met behulp van die rekenaar word 'n oplossing verkry.

INTRODUCTION

THIS paper presents an outline of a simulation study done by the Operations Research Group of African Explosives &Chemical Industries Limited. Although the numerical values given here are fictitious, in most cases they differ from the original values only by a constant factor. Therefore the results give a reasonably accurate picture of what happened in the original study. The conclusion reported is the same as that of the original study.

Simulation is now quite a common method of tackling the problem of determining how much storage capacity is required for a product. The basic question to be answered is: "If we had a storage capacity of x tonnes, what would be the effect?" And then, "If we had a little more than x, or a little less, would things be better or worse?".

One way of answering this sort of question is to build a model of the system with the storage in it and then use the model to determine the effects of various storage capacities. In this case the model consists of a set of mathematical and logical relationships between parts of the system, and these relationships are coded into a program for the computer. Then the computer can simulate alternative systems (i.e. alternative storage capacities) and keep track of the relevant results. Thus several alternatives can be compared and the "best" one chosen.

PROBLEM DESCRIPTION

One of the Company's production plants — part of a fairly new complex — has a production capacity of 400 tonnes per day. During the year there are planned shutdowns totalling four weeks, and for the remainder of the year the plant is expected to be available for 76.5% of the time. This means that it can be expected to produce approximately 103,000 tonnes in a year.

The local demand for the year was estimated at 69,000 tonnes. This was made up of demands by other Company plants as well as sales in the home market.

It was apparent, therefore, that capacity exceeded local demand by some 34,000 tonnes. Since the home market is expected to grow, eventually this spare capacity would be utilized locally. But there is a reasonably good export market for the material being produced and it was desired to export as much of this 34,000 tonnes per annum as possible.

The Company's Export Service Department had estimates of orders which AE and CI might be able to get, along with expected quantities and lead times. The export markets were divided into two groups:

Type A — markets with good profitability
Type B — markets with marginal profitability

There were storage facilities at the Factory to handle the packed product for the home market, but there were no bulk storage facilities. It is not possible to store material for the export market already packed because each customer requires his own special size of pack with his own markings on it. Therefore unless a bulk store was built, export orders could only be filled from production and it was expected that this would severely hamper our ability to compete for export orders.

The problem was:

Should AE and CI build a bulk store at the Factory?

The answer to this question depended on what effect a bulk store could be expected to have on our performance in the export markets. The problem was rephrased as follows:

Would a bulk store improve our export performance enough to justify the expense involved in building it?

METHOD OF INVESTIGATION

The problem had quite a number of highly variable factors which could be estimated in a probabilistic sense but were not known with certainty. The most important of these were:

1. The time interval between orders from type A export markets.
2. The size of these orders.

3. The lead time available for filling these orders.

4. The time interval between orders from type B export markets.

5. The size of these orders

6. The lead time available for filling these orders.

7. The pattern of breakdown of the main plant.

8. The pattern of breakdown of a feeder plant which supplies the raw material for the main plant. (A breakdown on the feeder plant causes a shutdown on the main plant.)

All these factors were stochastic variables, and because of this it was not possible to predict with certainty what would happen in a particular year.

To take account of the stochastic nature of the problem, it was decided to build a simulation model for the computer. The computer could then be used to simulate a number of hypothetical years of operation, first with no bulk store in the system and then with a bulk store of any desired capacity in the system.

This procedure would generate a range of results for each situation so that no single simulated year would be a sufficient basis for judgement. The intention was to try to detect any general tendency towards improved performance in the years when a bulk store was available and to get an indication of how much (if any) better export performance could be expected.

The reason for using a computer to do the simulation was that this made it possible to simulate a number of years of each situation within a reasonably short time.

THE MODEL

G.P.S.S. and Computer Simulation

There are several computer languages which have been constructed particularly for building computer simulation models. AE and CI had no experience with any of these, although the author had used a language called SIMSCRIPT prior to joining AE and CI. However, IBM in South Africa had considerable experience with a language called G.P.S.S. (General Purpose Simulation System), so it was decided to use this language. The model was therefore designed with G.P.S.S. specifically in mind.

Units of Measurement

G.P.S.S. is designed to handle the simulation of discrete entities, through discrete intervals of time. But the production operation was a continuous process which occurred at a rate of 400 tonnes per day. To simulate this continuous process using G.P.S.S. it was necessary to divide the production into discrete units. In particular, the production process was viewed as if material was produced in 10-tonne batches 40 times per day. Thus the time unit used by the simulation model was 1/40th of a day (i.e. 36 minutes).

The choice of this unit represented essentially a compromise between too large a unit — which could have led to spurious results — and too small a unit — which would have resulted in very long computer runs to simulate a year's activity.

Home Market Demand

The expected variation in home market demand was regarded as negligible when compared with the wide variation in possible export demands. Because of this the local demand was treated as deterministic — i.e. known with absolute certainty. The demand was expressed as a function of time, since the product has a somewhat seasonal demand pattern in Southern Africa.

Type A Export Orders

The data available from AE and CI's Export Services Department was used to construct probability distributions for

(a) Inter-arrival time of order queries from A markets

(b) Order quantity

(c) Lead time allowed for filling the order.

When an order query occurred, the model was designed to accept or reject the order according to a decision rule described in detail below. Basically, an order was rejected if the situation at that time was such that acceptance would have been likely to jeopardize the local market supply position.

The inter-arrival time distribution was assumed to be exponential in form. That is, the probability of time t between successive orders was given by the function

$$P(t) = \frac{1}{m} e^{-t/m}$$

where m is the mean-time between orders.

Type B Export Orders

Export orders in group B differed from those in group A in that the type B orders where expected to be only marginally profitable. But the characteristics of these orders were also different. In general, the orders available from markets in group B tended to be fewer in number but had larger order quantities and longer lead times than those from the A markets.

Once again, the data available from our Export Services Department was used to construct probability distributions for

(a) Inter-arrival time of order queries from B markets.

(b) Order quantity

(c) Lead time allowed for filling an order

When an order query occurred the model used essentially the same decision rule as for type A orders to decide on rejection or acceptance of the order. The criterion for acceptance could be made more stringent, however, since the type B orders were not very profitable.

The inter-arrival time distribution was again assumed to have an exponential form, but in the case of type B orders the mean inter-arrival time m was a different constant.

Main Plant Breakdown

The model generated breakdown of the main plant according to a binomial distribution with p = 0.120. The duration of each breakdown was assumed to be one day (i.e. 40 simulation time periods), and the probabilities of breakdowns on any two days were assumed to be independent. Thus the probability of a two-day breakdown was $(.12)^2$ = .0144, of a three-day breakdown was $(.12)^3$ = .0017, and so on.

Feeder Plant Breakdown

The pattern of breakdowns on the feeder plant was quite different from that of the main plant. The time interval from the end of one breakdown to the beginning of the next was assumed to have an exponential distribution with a mean of approximately 3 months. The duration of a breakdown was assumed to have an exponential distribution with a mean of 2 weeks.

Plant Shutdown

The model shut the main plant down for a total of 28 days at pre-determined times during the year, corresponding to planned shutdowns at the Factory. During times of shutdown or breakdown local demand was satisfied from stocks of the packed product and export orders could be satisfied out of the bulk store when this facility existed in the system being simulated.

Operating Rules

The operating rules built into the model were necessarily simplified, but were felt to be a good approximation of the way in which the system would be operated in practice.

There were two control levels associated with the local market buffer stock. These may be termed the minimum level and maximum level. The operating rules were set up to try to achieve the result that the stock level would not fall below the minimum level, which was essentially a safety stock. The maximum level was used to decide when there was enough stock stored in packs for the home market and above this level excess production material was put into bulk store (if one was present in the system).

Both the minimum and maximum levels were expressed in terms of time units and both could be changed from run to run. Typically however, the minimum level might be two weeks' stock and the maximum four weeks' stock. Also, the simulation could be started with some given amount of product already in stock in both forms — packs and bulk.

The model operated on the assumption that as long as the home market buffer stock did not fall below the minimum acceptable level, export orders represented the highest priority demand for the plant's production. Thus, at any time when there was an export order to be filled it was filled with all the resources of the plant **unless** the safety stock of packed product for the local market was below the minimum control level. In this latter case, production was used to build up the buffer stock to the minimum level before being used to fill export orders.

When material was available in bulk store and the local buffer stock had fallen below the minimum level, then provided there was no export order to be filled the bulk store material could be packed for the local market until that stock got up to the minimum safety stock required. Also, if the plant was broken down and the buffer stock was below the maximum control level, then the plant's packing unit would be used to pack material from bulk store (if it was available) for the home market stock until this reached the maximum control level or until the plant returned to operation.

Order Acceptance Decision Rule

An export order was only accepted by the plant if it was expected that after completing this order the stock of home market material would still be at an acceptable level. In order to decide this, a calculation was made of **Spare Resources** as follows:-

Quantity of product at present in bulk store

+ (76.5% of 400 tonnes X order lead time in days)

− total quantity of export orders already accepted but not made

− (quantity required for the home market during the lead time

+ required home market stock at the end of the lead time

quantity presently in stock for home market)

The last of these four terms was only included in the calculation if it was positive, i.e. if the local buffer stock was not already bigger than it had to be at the end of the lead time by an amount that exceeded the requirements during the lead time.

It should be mentioned here that the 'required buffer stock at the end of the lead time' was not necessarily the minimum control level mentioned previously. It might be higher, depending on how conservative a decision rule was wanted. For example, by setting this at 4 weeks' stock instead of 2 weeks' stock the rule would only accept orders if it was very safe to do so.

The decision rule for accepting or rejecting an order query was simply this:

> If Spare Resources exceed Order Quantity, accept. Otherwise, reject.

RESULTS

During the testing stage several runs were done with different operating rules and buffer stock control levels. The rules in the final version of the model were those outlined in the preceding section. The control levels for the home market buffer stock were eventually fixed at two weeks (minimum) and three weeks (maximum). The required home market stock used in the decision rule for export order acceptance was four weeks.

The results reported here are from two simulation runs, each of which involved 10 replications of one simulated year's activity. The year was started with 3,100 tonnes of packed stock for the local market and nothing in bulk store. The only difference between the two runs was that Run 1 simulated a system containing no bulk store while Run 2 simulated a system containing a bulk store of effectively infinite capacity.

Table I shows the average export performance. There was no significant difference in the total tonnage exported between the two cases. It is interesting to note, however, that when a bulk store was available the failure rate dropped from 3% to 2.5%.

Table II shows the results of the 10 replications in more detail. The standard deviations are important as a measure of the value of each mean as a predictor. For example, in the particular set of 10 replications the annual production averaged 109,105 tonnes. But the range over the 10 replications was from a low of 96,131 tonnes to a high of 120,890 tonnes and the standard deviation was 7,873 tonnes. Therefore, even if we limit ourselves to an interval of one standard deviation about the mean, we would not be surprised to find production in any particular year anywhere in the interval from 101,232 tonnes to 116,978 tonnes. And one standard deviation is not really enough. It is more usual to use an interval of 2 or 3 standard deviations on either side of the mean value.

In Run 2 the average contents of the bulk store over the entire period was only 634 tonnes. The absolute maximum contents was 10,283 tonnes, although the average of the maximum over the 10 replications was only 6,117 tonnes. Note that the value of 2,781 tonnes shown in Table II is the average **end-of-year** contents of bulk store. This is naturally higher than the over-all average of 634 tonnes since toward the year-end local demand slacks off and more can be put into bulk store instead of packed stock.

What appeared to happen was that the availability of a bulk store facility did not improve export performance in Run 2 over Run 1 significantly because the bulk store facility was not used to the extent that might have been expected. Apparently the lead times available for filling export orders were sufficient to allow most of them to be filled from production in Run 1 without jeopardizing the home market.

TABLE I

EXPORT PERFORMANCE

(Average Results from 10 Replications of a Simulated Year)

ALL QUANTITIES IN METRIC TONNES.

	RUN 1 NO BULK STORE	RUN 2 'INFINITE' BULK STORE
Export Orders Turned Down	58,303	57,563
Export Orders Made On Time	36,686	37,654
Export Orders Not Made On Time	1,154	926

TABLE II

STATISTICAL REPORT OF RESULTS FROM TEN REPLICATIONS OF A SIMULATED YEAR - ALL QUANTITIES IN METRIC TONNES

	RUN 1 NO BULK STORE		RUN 2 'INFINITE' BULK STORE	
STATISTIC	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
A MARKETS				
Orders Turned Down	5,579	5,398	5,306	5,498
Orders Made On Time	18,223	6,203	18,357	6,270
Orders Not Made On Time	650	2,104	603	2,123
B MARKETS				
Orders Turned Down	52,724	23,917	52,257	24,731
Orders Made On Time	18,463	10,729	19,297	11,718
Orders Not Made On Time	503	1,535	323	1,170
Year-End Contents of Bulk Store	0	0	2,781	4,795
Total Production of Export	36,686	8,413	37,654	6,743
Production for Local Market	72,419	5,107	71,451	1,895
Total Annual Production	109,105	7,873	109,105	7,873

CONCLUSION

No significant difference was found in the total tonnage exported when a bulk store was included in the simulated system. A slight improvement in performance was indicated by the drop in the rate of orders which we failed to make by the specified due dates. This failure rate dropped from 3% of tonnage to 2.5% of tonnage.

The study clearly showed that the cost of building a bulk store (estimated at close to R200,000) could not be justified by improved export performance.

ACKNOWLEDGEMENT

Thanks are due to the Directors of African Explosives and Chemical Industries Limited for permission to present this paper.